Boosted objects

Vincent Theeuwes

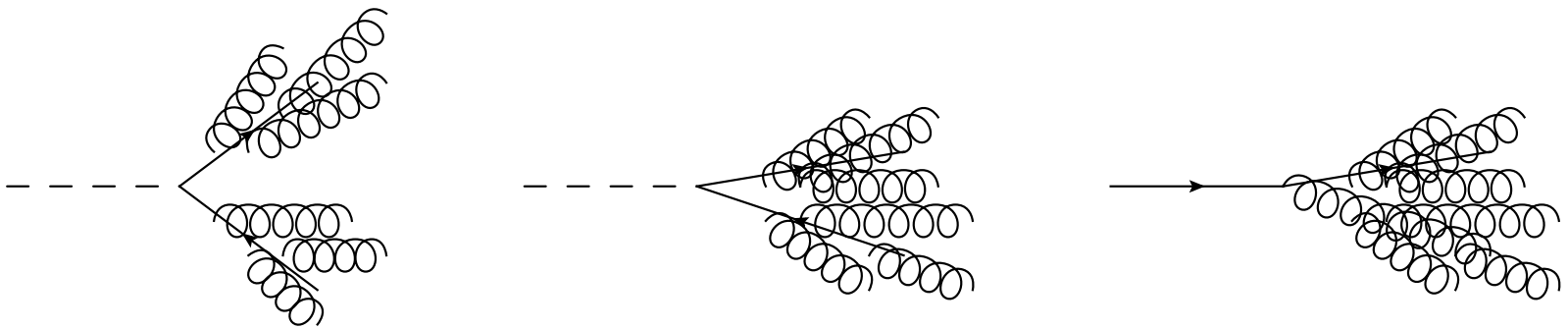
Georg-August-University Göttingen

TOP Paris, 24-05-2018

GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

Boosted particles

- LHC energy much larger than heavy particle masses
- Massive particles predominately produced boosted ($p_T \gg m$)
- Harder to distinguish from QCD jets



Non-perturbative contributions

Many effects cannot be described by perturbation theory:

- Hadronization effects
- Multi-parton interactions
- Pile-up

Jet substructure

- Many jet substructure techniques developed; Grooming and Tagging
  - Grooming: Clean up jets removing soft radiation
  - Tagging: Identify objects
- Created with the purpose of distinguishing signal from background
- Removes soft wide-angle radiation
- Can also help reduce non-perturbative corrections

mMDT & Soft drop

Main technique we will deal with is soft drop:

[Larkoski, Marzani, Soyez, Thaler; '14]

$$\frac{\min\left(p_{T,1}, p_{T,2}\right)}{p_{T,1} + p_{T,2}} > z_c \left(\frac{\Delta R_{12}}{R}\right)^{\beta}$$

Makes use of Cambridge/Aachen clustering.

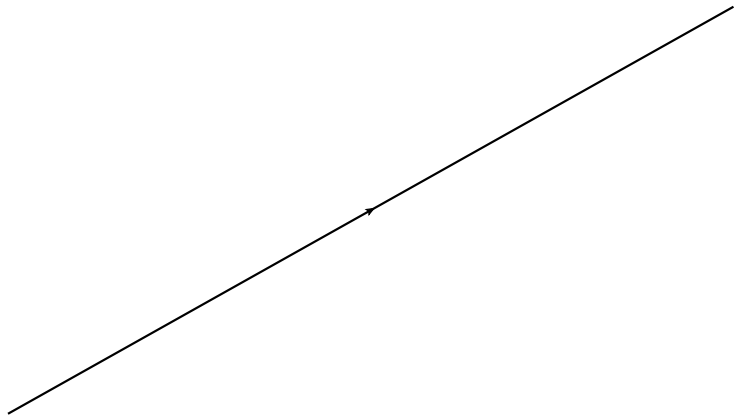
[Dokshitzer, Leder, Moretti, Webber; '97][Wobisch, Wengler; '99]

Reduces to modified Mass Drop Tagger (mMDT) for $\beta = 0$

[Dasgupta, Fregoso, Marzani, Salam; '13]

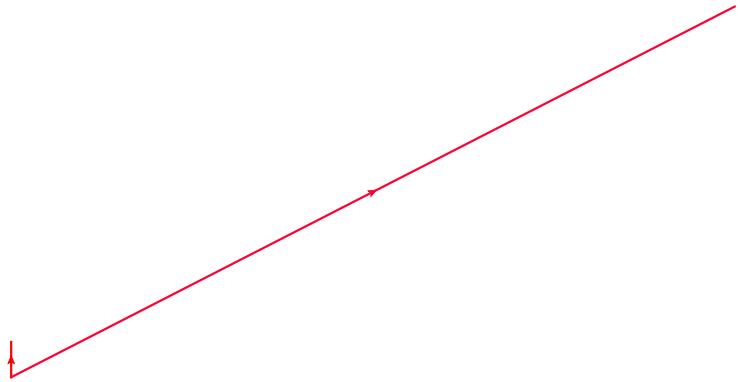
Full Soft drop

1) Decluster the last step
2) Check the soft drop condition for this splitting
3) If it fails drop the softest and repeat
4) If it passes finish the grooming



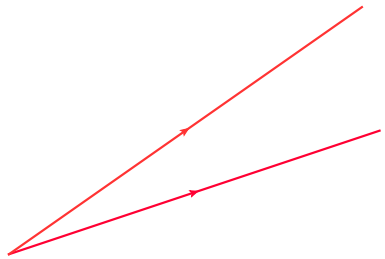
Full Soft drop

1) Decluster the last step
2) Check the soft drop condition for this splitting
3) If it fails drop the softest and repeat
4) If it passes finish the grooming



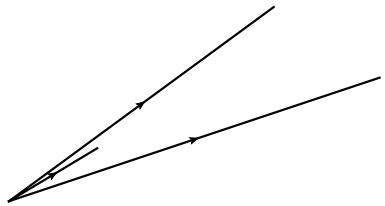
Full Soft drop

1) Decluster the last step
2) Check the soft drop condition for this splitting
3) If it fails drop the softest and repeat
4) If it passes finish the grooming



Full Soft drop

1) Decluster the last step
2) Check the soft drop condition for this splitting
3) If it fails drop the softest and repeat
4) If it passes finish the grooming

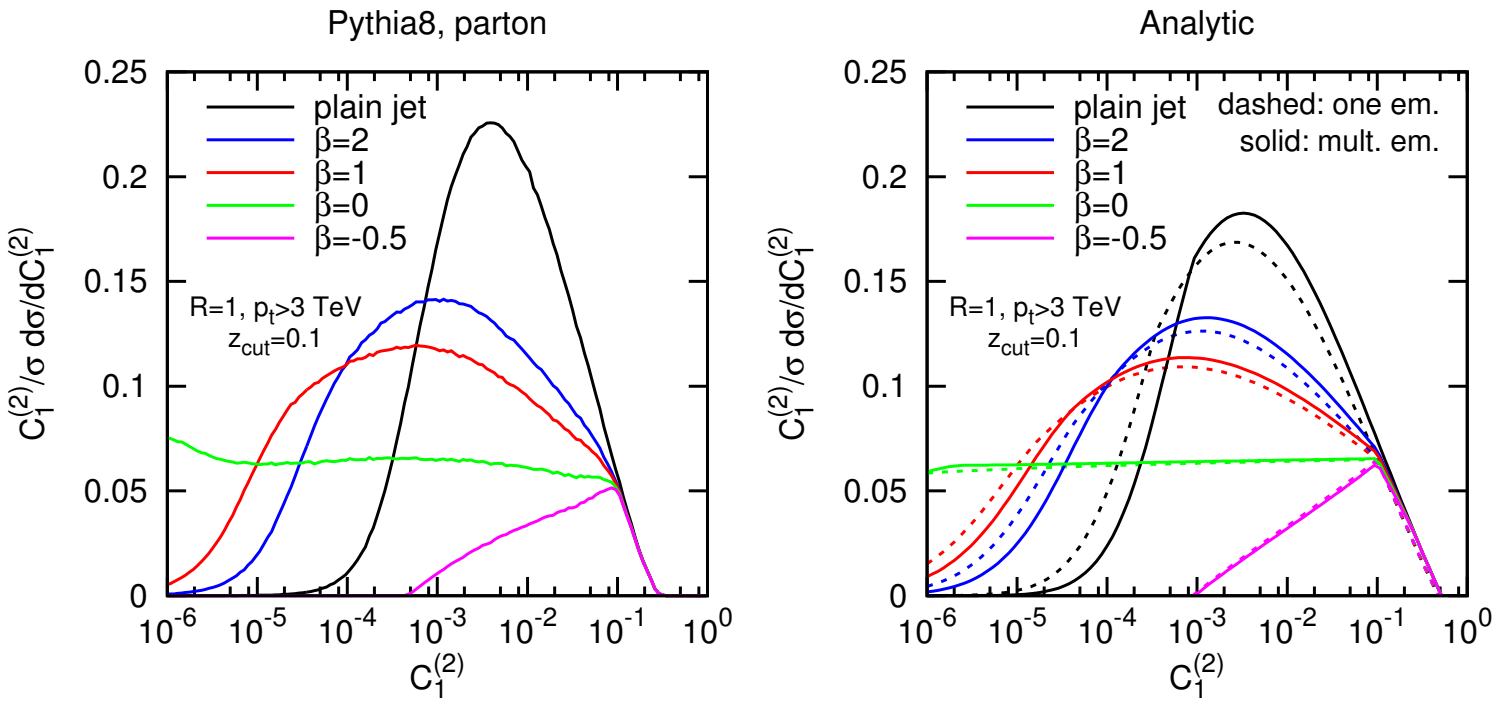


Need for resummation

For boosted jets, great separation of scales $p_T \gg m$ leads to large logarithms:

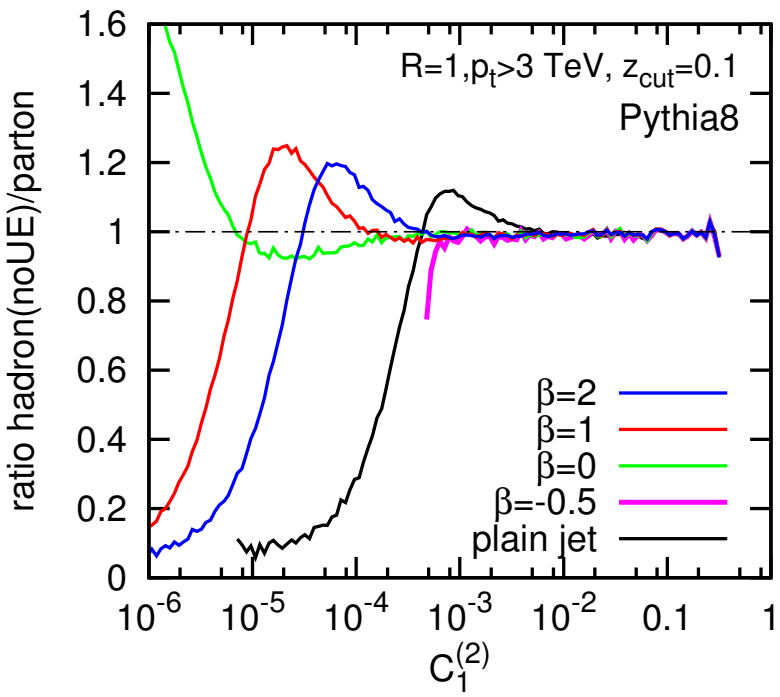
$$\log\left(\frac{m_J^2}{p_T^2 R^2}\right)$$

Large logarithms need to be resummed.

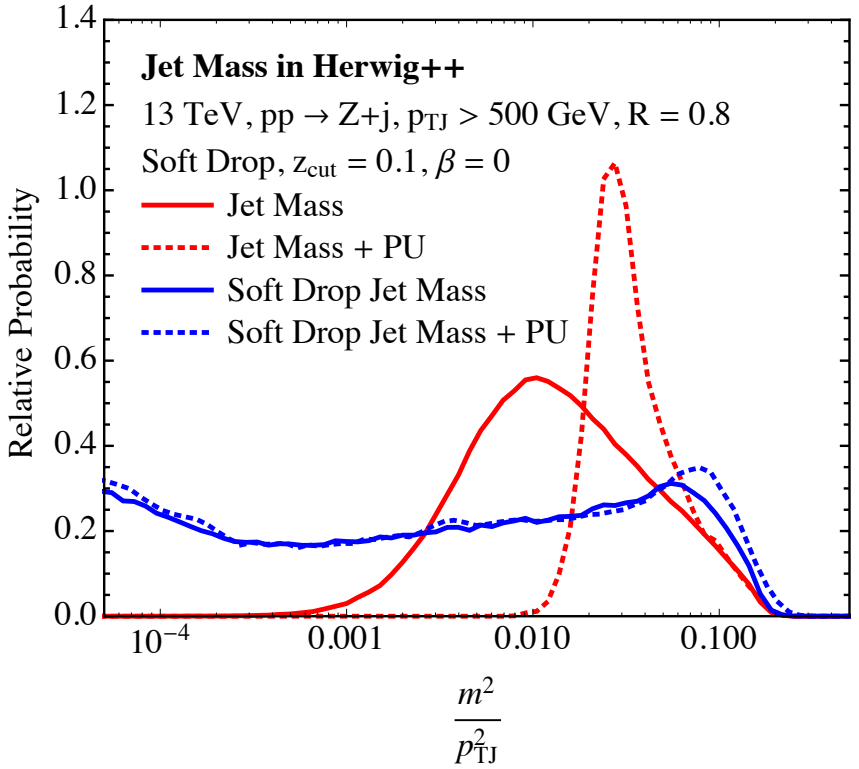


[Larkoski, Marzani, Soyez, Thaler; '14]

Reduction in NP corrections



[Larkoski, Marzani, Soyez, Thaler; '14]



[Frye, Larkoski, Schwartz, Yan; '16]

Further Work

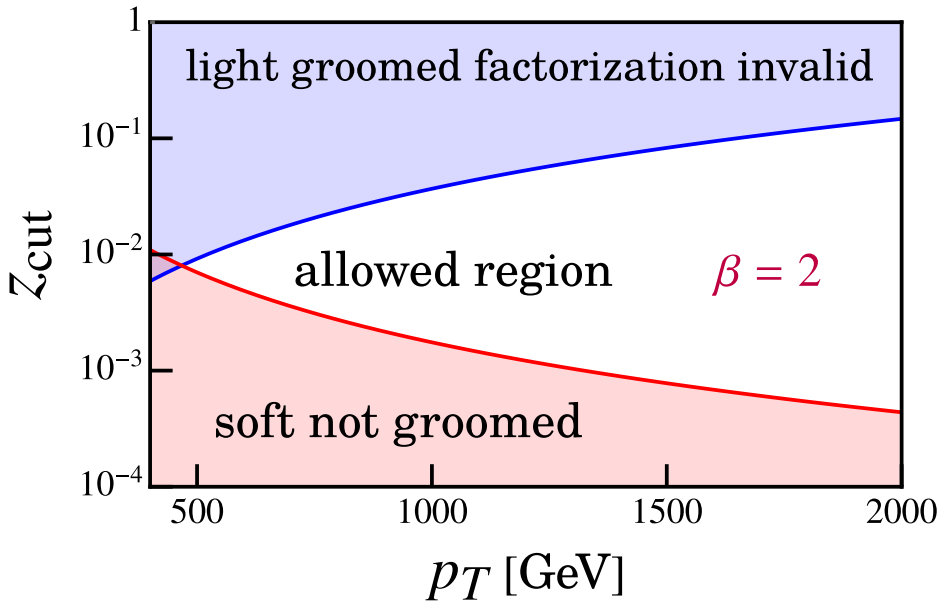
- Computation of soft drop using SCET at NNLL accuracy approximated for $e_2^{(2)} \ll z_{cut}$ *[Frye, Larkoski, Schwartz, Yan; '16]*
- Calculation in dQCD including finite $z_{\rm cut}$ effects *[Marzani, Schunk, Soyez; '17]*
- Good agreement to experiments *[CMS;'17] [ATLAS;'17]*
- Application to top quark mass measurements *[Hoang, Mantry, Pathak, Stewart;'17]*
- Including jet radius resummation in SCET *[Kang, Lee, Liu, Ringer; '18]*
- And $\alpha_{\rm s}$ measurements at LHC *[Les Houches;'18]* and e^+e^- *[Baron, Marzani, VT; '18]*
- Many others ....

Light grooming

[Hoang, Mantry, Pathak, Stewart;'17]

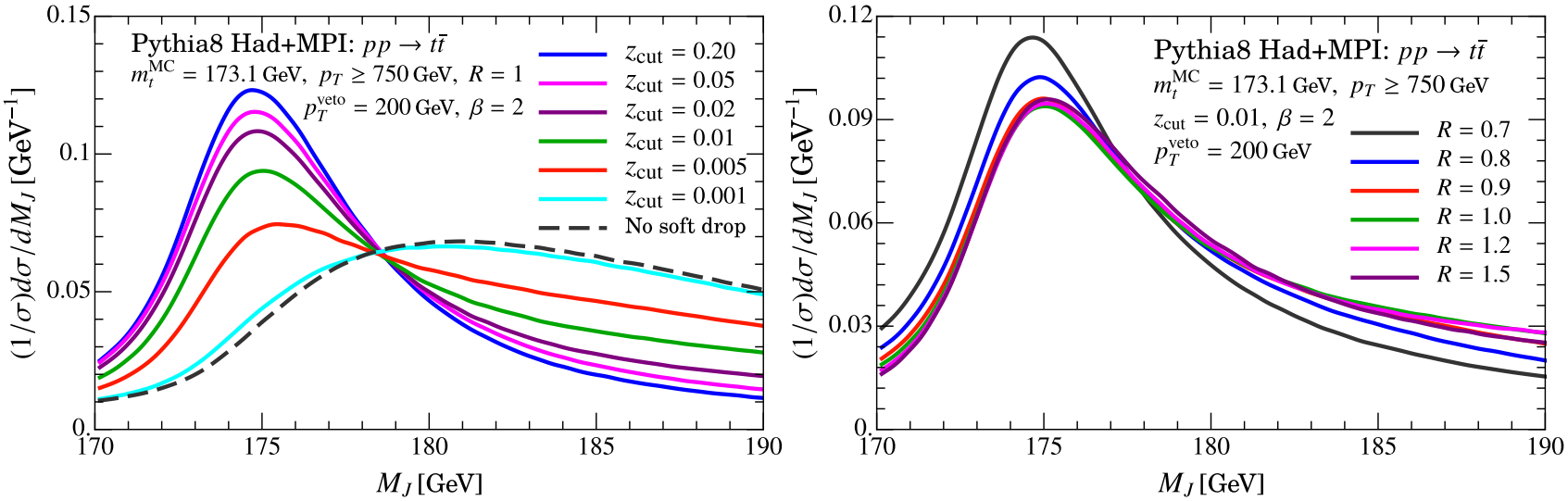
$$\frac{\Gamma_t}{4m_t}\left(\frac{Q}{4m_t}\right)^{\beta} \gtrsim z_{\rm cut}$$

$$z_{\rm cut}^{\frac{1}{2+\beta}} \gg \frac{1}{2}\left(\frac{\Gamma_t}{m_t}\frac{4m_t^2}{Q^2}\right)^{\frac{1}{2+\beta}}$$



z_{cut} and R dependence

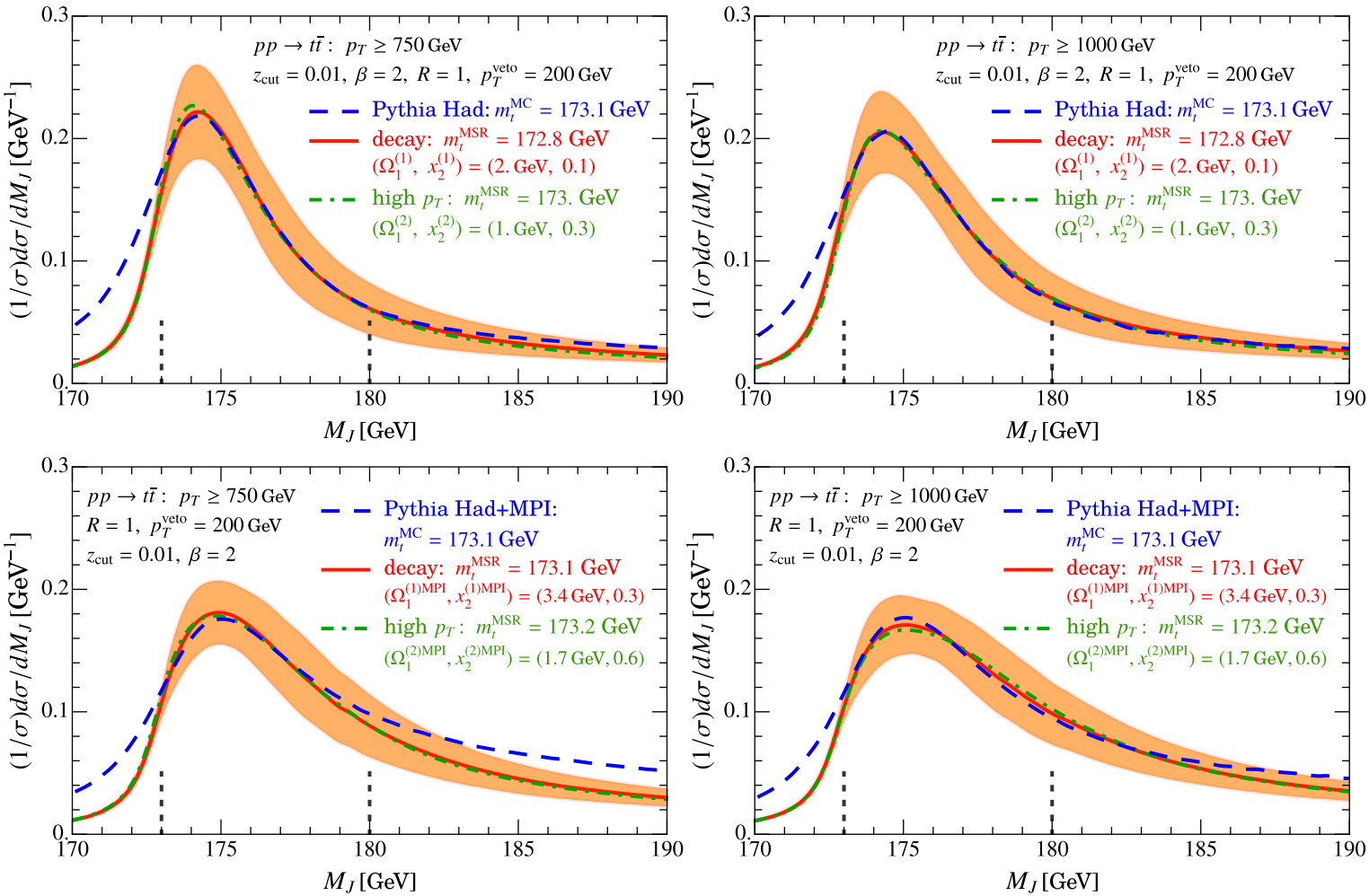
[Hoang, Mantry, Pathak, Stewart;'17]



- Visible transition in jet mass peak
- Significant reduction in R dependence

Theoretical predictions

[Hoang, Mantry, Pathak, Stewart;'17]

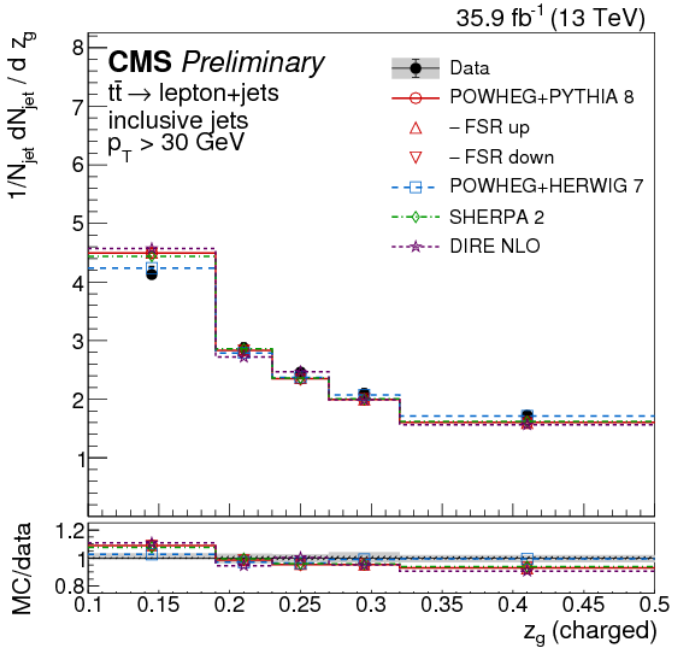


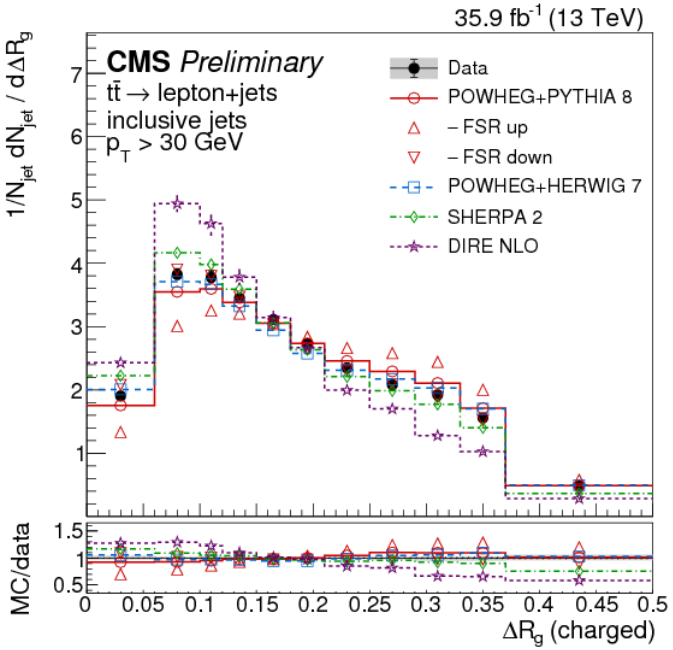
Good agreement in peak region, higher accuracy for low and high M_J

CMS groomed top cross section

Analyzing the hard splitting that passes soft drop

[CMS;'18]

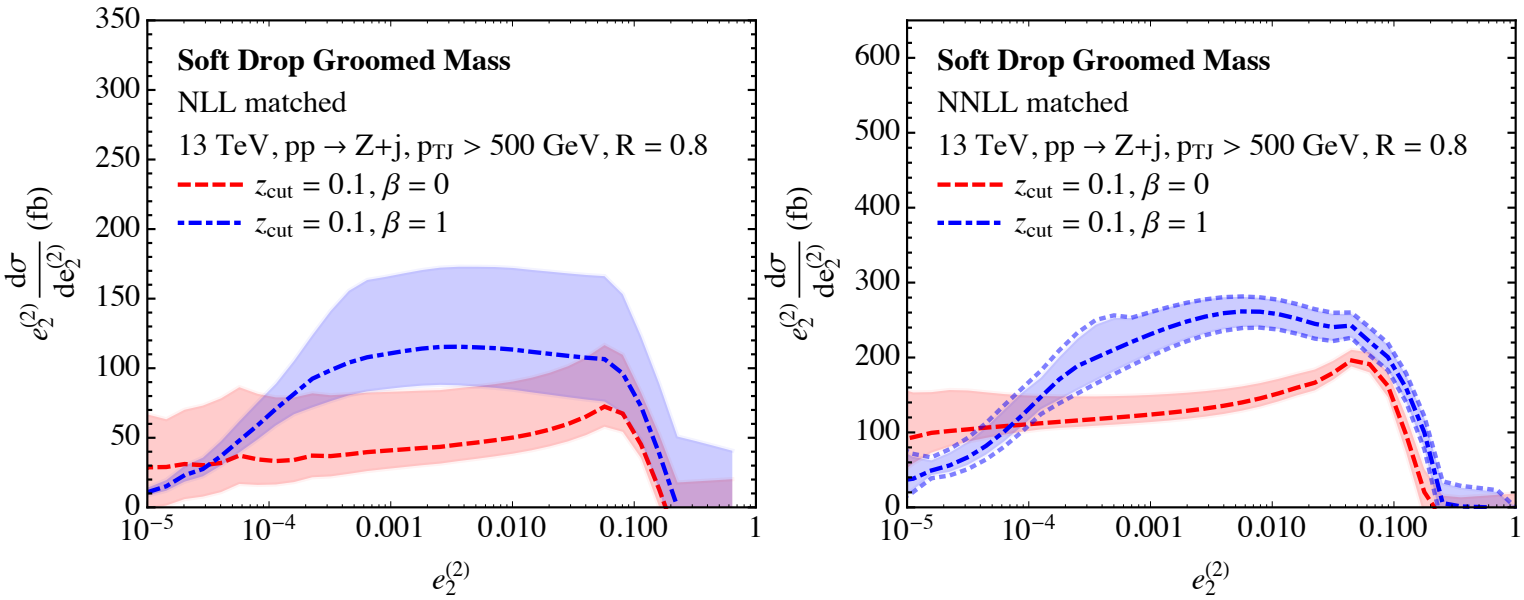




- Good agreement for z_g, directly probes splitting function
- Further study needed for ΔR_g

Computation at NNLL accuracy

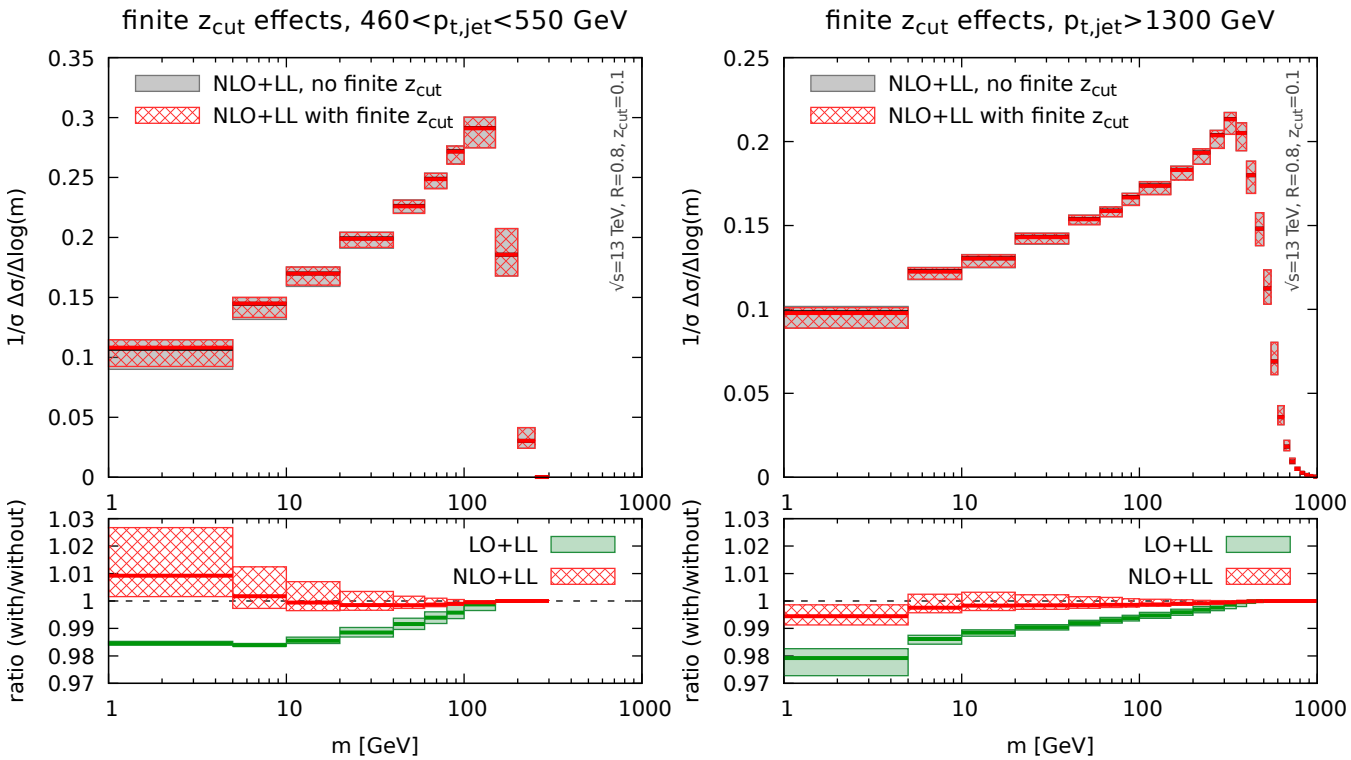
- Computation of soft drop using SCET at NNLL accuracy
  [Frye, Larkoski, Schwartz, Yan; '16]
- Approximated for $e_2^{(2)} \ll z_{cut}$



- Significant reduction in uncertainty

Finite z_{cut} effects

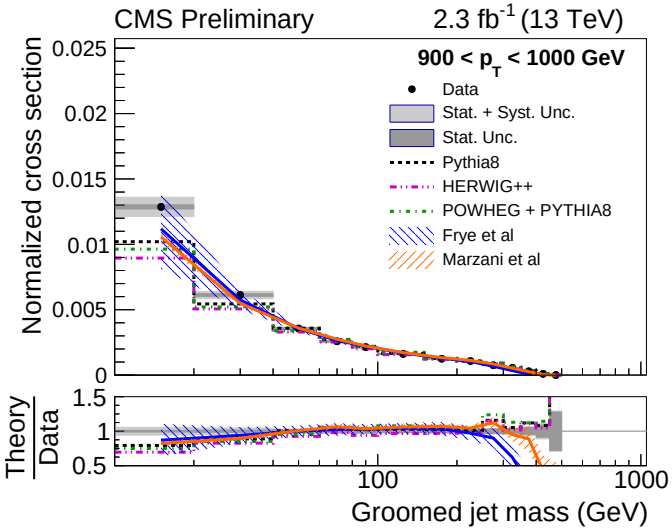
Calculation in dQCD including finite z_{cut} effects *[Marzani, Schunk, Soyez; '17]*:



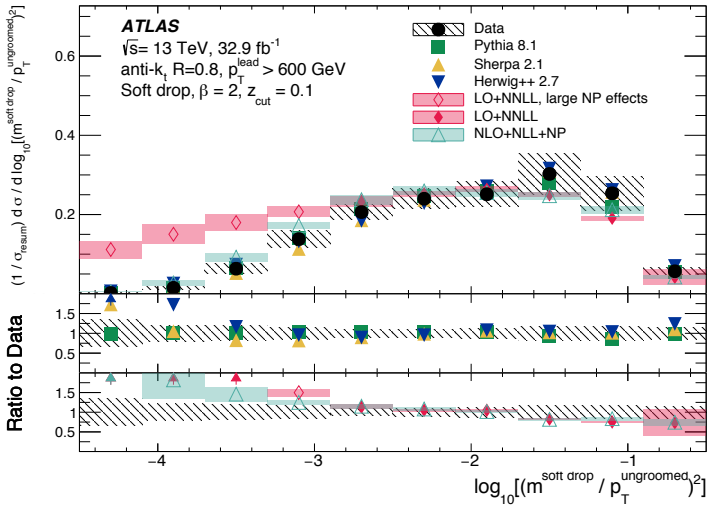
Percent level corrections for $z_{\text{cut}} = 0.1$, but can be larger for other values

Measurements

Recent comparison to LHC data:



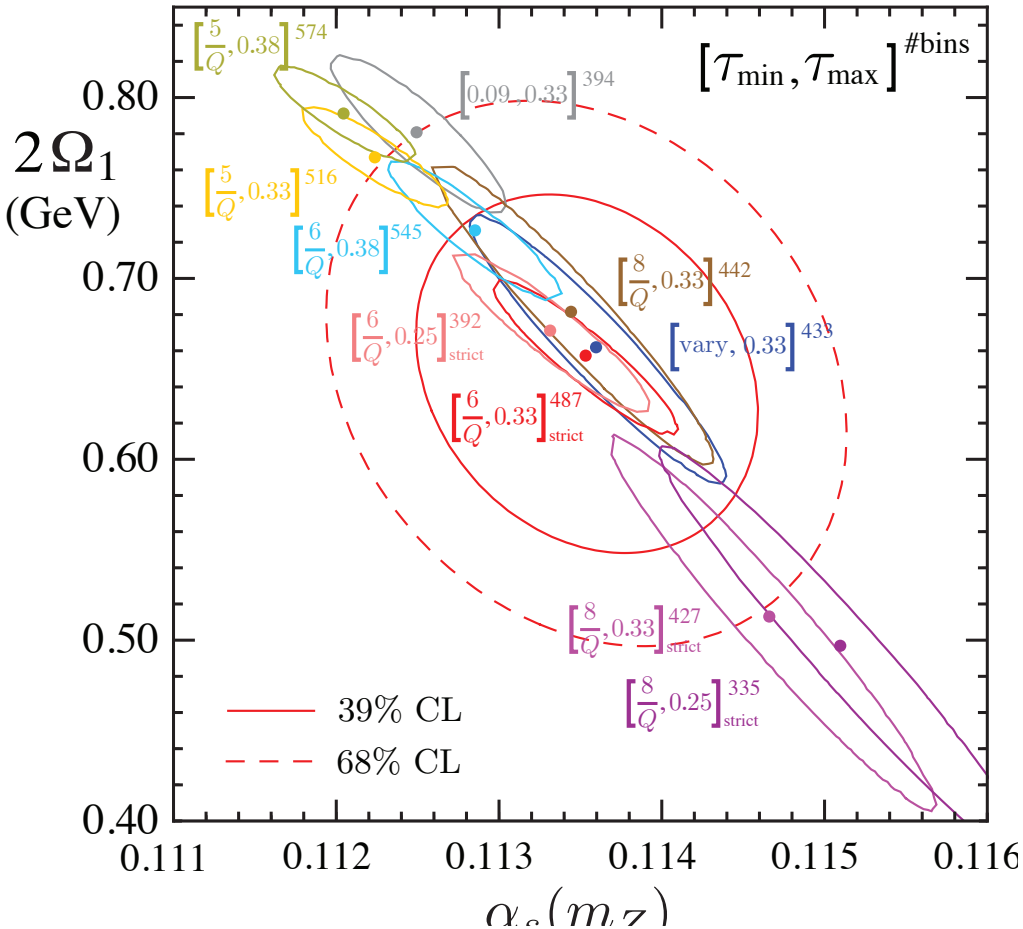
[CMS;'17]



[ATLAS;'17]

Good agreement with Data

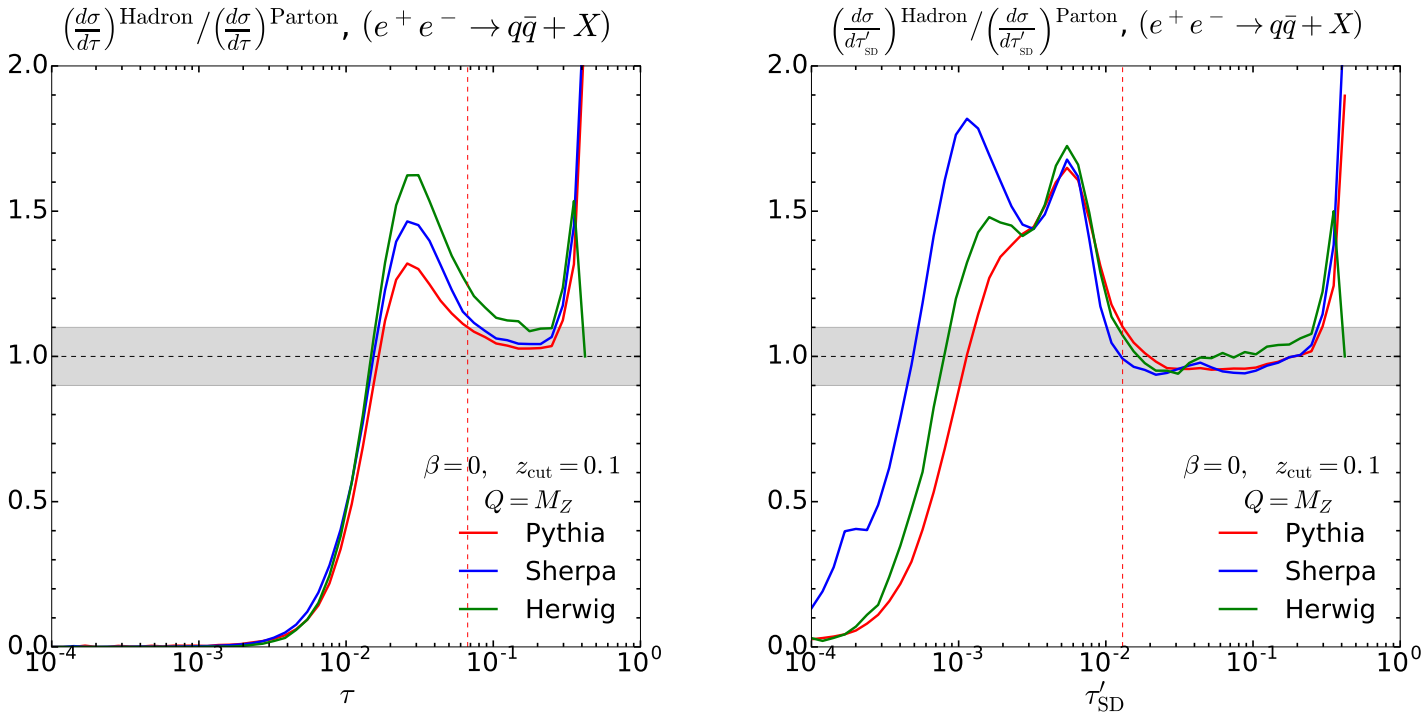
NP contributions



[Abbate, Fickinger, Hoang, Mateu, Stewart; 10]

MC studies

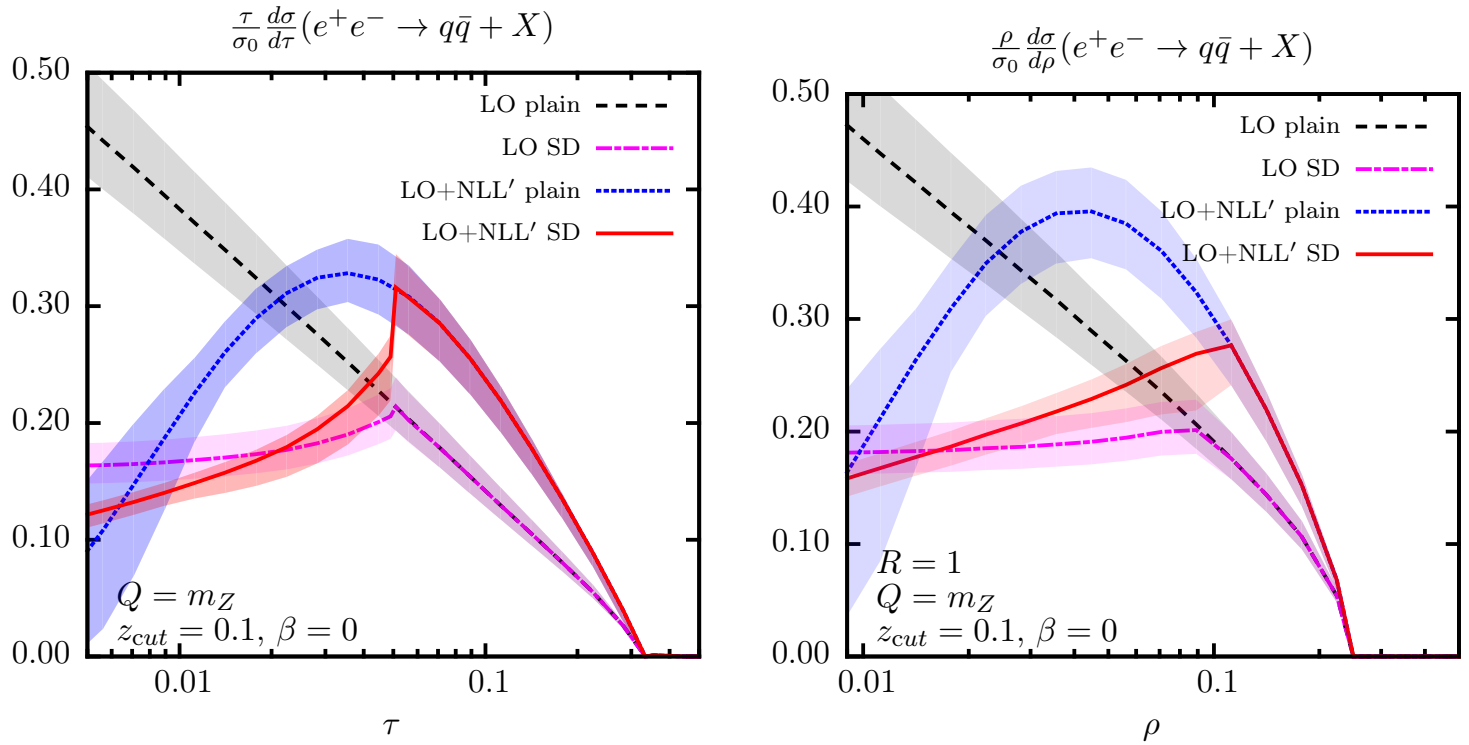
[Baron, Marzani, VT; '18]



Non-perturbative corrections above 10% from $\tau \simeq 0.07$ to $\tau \simeq 0.001$

Resummation results

[Baron, Marzani, VT; '18]



- Transition corrections are important for thrust
- Other observables allow for a reduction in transition point effects

Summary

- There is a rich world of jet substructure techniques applicable to boosted jets
- Soft drop is widely usable for many different studies
- Ongoing efforts to further increase theoretical accuracy in order to apply to precision measurements
- A variety of experimental studies being performed

Summary

- There is a rich world of jet substructure techniques applicable to boosted jets
- Soft drop is widely usable for many different studies
- Ongoing efforts to further increase theoretical accuracy in order to apply to precision measurements
- A variety of experimental studies being performed

Thank you for your attention